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TURBULENT WAKE GAS ANALYZER PROGRAM

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ABSTRACT

Presented herein is a description of the design and operation of the Turbulent Wake Gas Analyzer, a system built by Bendix to extract and analyze gas samples from the wake of a ballistic projectile. When a projectile is fired past the sampling probe inlet of the system, the short-lived ions and neutral molecules in the turbulent wake of the missile are ingested by the probe and transformed into a molecular beam. This beam enters a time-of-Flight Mass Spectrometer where a complete time history analysis of the growth and decay of the short-lived wake products is performed.

GENERAL DESCRIPTION

The Turbulent Wake Gas Analyzer was designed and constructed to extract and analyze gas samples from the wake of a ballistic projectile. As shown in Figure 1, a complete gas handling and analysis system is mounted with a short section of ballistic chamber on an elevating platform. The platform is capable of adjusting the sample extraction nozzle relative to the projectile path. The gas handling subsystem, which extracts the gas from the wake, is a molecular beam generator of unique design. A special Bendix Time-of-Flight (TOF) Mass Spectrometer with offset oscilloscope trace capability for conveniently recording rapid fluctuations in gas sample composition forms the gas analysis subsystem. The vacuum components and spectrometer electronics are protected by a fail-safe and vacuum-control network.

THE BALLISTIC EVENT

Spherical and conical projectiles, 5 mm to 16 mm in diameter are injected into the ballistic range at velocities approaching 20,000 ft/sec. Each projectile passes through a 150-foot-long instrumented chamber 12 inches in diameter that contains, typically, nitrogen or dry air at room temperature and at an ambient pressure of from 5 torr to 160 torr. As a hypersonic sphere moves through the controlled atmosphere, a well-known flow pattern is produced that consists of a bow wave, a secondary shock wave, and a turbulent wake. The bow wave, preceding the secondary shock and turbulent wake, is a region of a compressed, high-temperature gas where temperatures may range well beyond 10,000°K near the projectile axis.

Although the ion and neutral molecular products of the high-temperature chemistry of the shock front are of scientific interest, the important products of the interaction chemistry are found in the turbulent wake. The ion and neutral composition of the wake is of extreme importance because it relates to and even controls the free electron density in the wake. The speed of the projectile, the composition of the ambient atmosphere, and the surface composition of the projectile all have a significant effect on the chemical ion and neutral species in the wake. In addition, the projectile speed and size control the specific concentration levels. It is anticipated that the wake of a nonablating projectile in clean air will contain the species NO, O, O_3, N_2^+, NO^+, NO_2^-, O^-, and O_2^-.

The properties of the shock, the wake, and the composition are extremely short-lived. In 0.165 msec after a 1-cm-diameter sphere passes an observer at 20,000 ft/sec, it has progressed 100 cm down the ballistic range; the hot bow shock wave has long since passed; the turbulent portion of the wake has expanded to a diameter of 4 to 5 cm; the environmental temperature has dropped to below 4500°K; the free electron density has reached a maximum and is decaying rapidly; and the formation of ion and neutral species in the wake is nearing completion. Since the mass

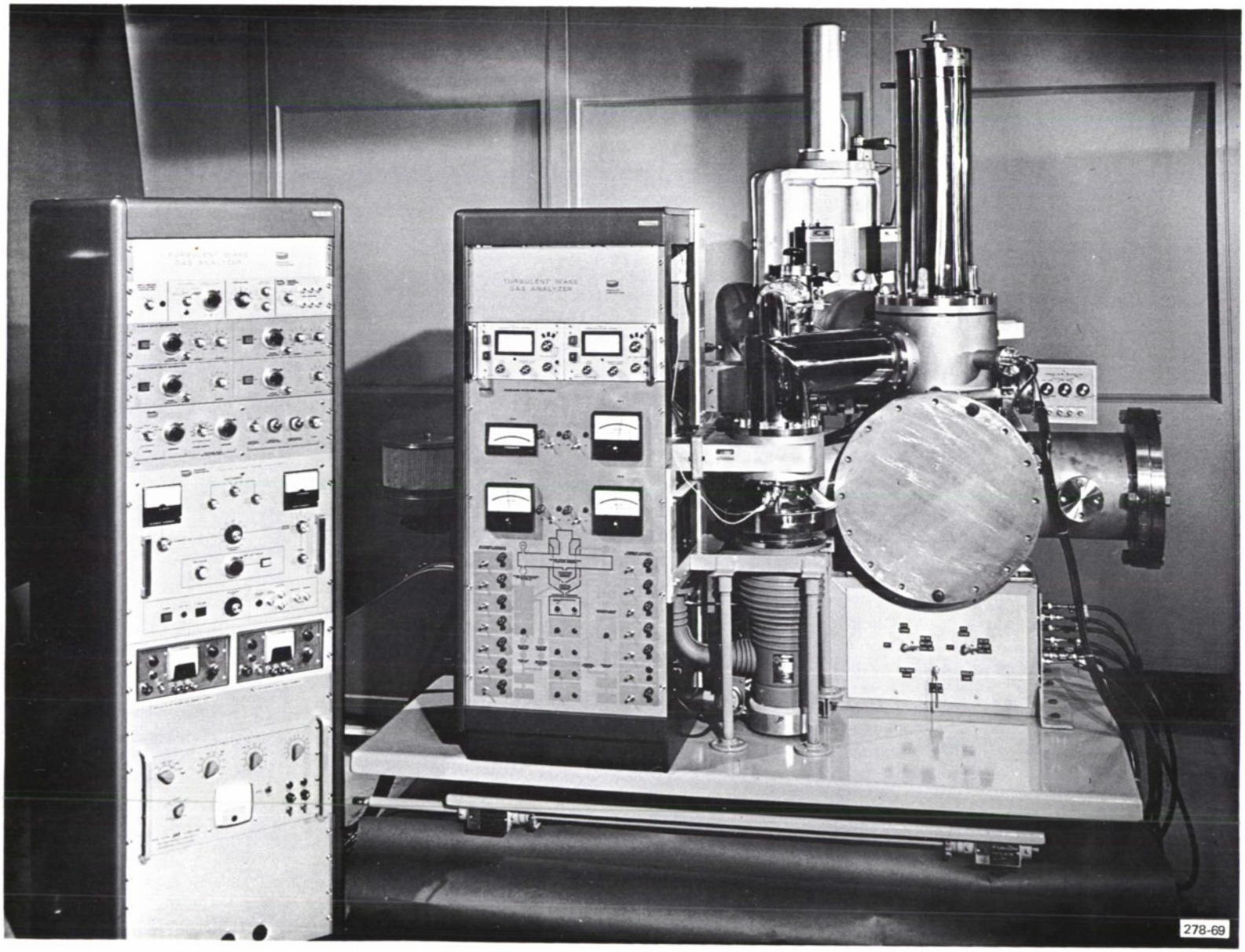

Figure 1 - Turbulent Wake Gas Analyzer

motion of the gaseous wake is subsonic, ion concentrations begin to fall rapidly after a few msec, and the products in the wake are largely dissipated after 50 to 100 msec. Therefore, a complete analysis of the buildup and decay of these products must be performed during this 50 to 100 msec period. Because of the short lifetime of the constituents, only positive ions, negative ions, or neutrals may be analyzed during a single ballistic shot.

THE ANALYZER SYSTEM

A schematic of the Turbulent Wake Gas Analyzer system is shown in Figure 2. The design, dictated by requirements and constraints discussed below, features a molecular beam generator gas inlet probe inserted into the top of a movable transition section of ballistic chamber. This probe is oriented to sample the upper portion of the projectile wake. Gas constituents from the wake will flow up through the probe into the ion source of the mass spectrometer. The bulk of the neutral gas load flowing through the probe will be trapped and pumped away by a liquid helium cryopump located above the ion source in the path of neutral gas flow. Commensurate with this arrangement, the spectrometer flight tube is oriented in a horizontal position.

Based on the temporal properties of the wake, it was necessary to locate the plasma probe entrance rather close to the projectile trajectory to ensure a sufficient sampling of the ion and neutral species. The uncertainty of the trajectory suggested that the probe tip be located at least two projectile body diameters from the ballistic range axis to avoid probe damage. To implement an effective study of the wake for different projectile geometries and sizes, the radial location of the probe relative to the ballistic range axis has a continuously adjustable range of four inches. No clear scientific requirement presently exists governing the orientation of the probe gas flow axis. Based on a desire for simplicity of design of the probe/ballistic chamber interface structure and the need for monitoring the radial position of the inlet probe, it was convenient to orient the probe gas flow axis perpendicular to the ballistic chamber axis. In addition, the external probe housing exposed to the shock wave and turbulent wake was streamlined to keep the probe interaction with the ballistic shock wave at a minimum.

The inlet probe is designed to ingest sample plasma at a flow rate sufficient to provide at the spectrometer ion source output at least 1 to 10 ions or neutrals of each specie per instrument cycle. The internal design of the probe meets the requirements for continuous sampling of the gas in the ballistic chamber, where ambient total pressures will range from 5 torr to 160 torr. Since the mass spectrometer will operate at pressures of 10^{-8} torr or below, the probe and associated pumps are designed to provide the proper pressure transition from the ballistic chamber to the spectrometer as well as function as a molecular beam generator. By significantly reducing the intermolecular collisions

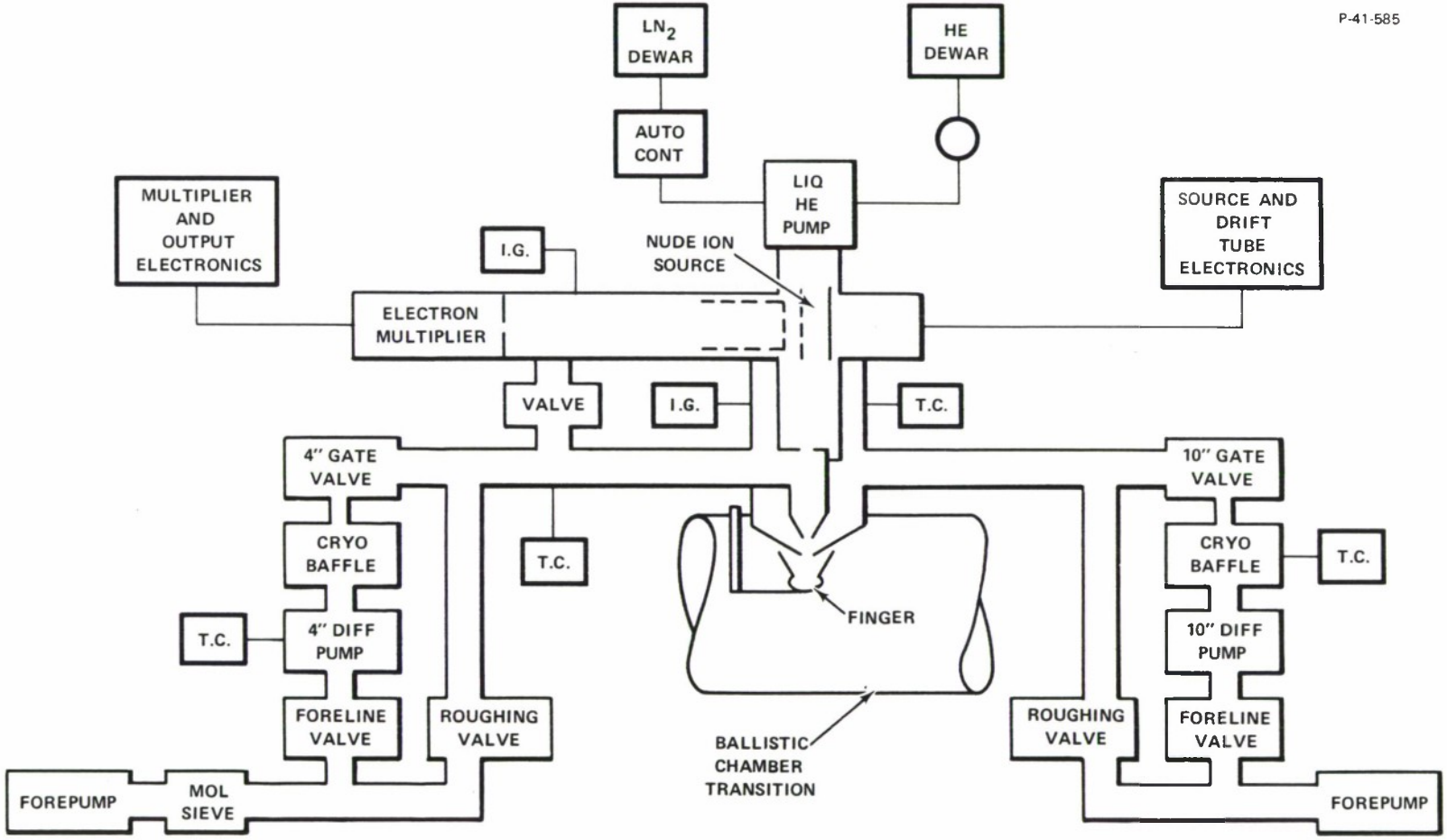

Figure 2 - Mass Spectrometer/Plasma Probe System Schematic

within a very short distance inside the probe, this generator preserves or freezes the state of ion and molecular chemistry as the ions and neutral gas molecules proceed into the spectrometer for analysis.

The standard TOF mass spectrometer normally analyzes neutral gas molecules by transforming the neutrals into positive ions by electron impact in the TOF ion source. However, for direct analysis of either positive or negative ions, modifications were made to the electrical and magnetic fields in the instrument. Both positive and negative ion analyses require the removal of the TOF ion source magnets. Although positive ion analysis may require only a slight change in the deflection plate field in the flight tube, negative ion analysis requires a polarity reversal of the electric field in the source, flight tube, and multiplier.

The current technique for "ions" analysis using the Bendix TOF Mass Spectrometer is to inject ions and neutrals from the plasma probe into the source at right angles to the spectrometer flight tube axis. Groups of ions issuing from the probe are pulsed out of the source and accelerated into the flight tube where the typical TOF analysis is performed. The flow of ions through the probe must be interrupted by a suppression electrode or ion deflector while the ions pulsed from the source are accelerated and analyzed in the flight tube. Neutral gas ions are not present since the ionizing electron beam does not operate during "ion" analysis. The suppression technique is also used when analyzing neutrals to block ions from entering the spectrometer.

A typical spectrometer operating with a nude source analyzes the directed particle flow as well as back-scattered neutrals. To minimize the back scatter and the effects on spectral data, a cryopump opposite the outlet of the plasma probe is provided to swallow the stream of particles.

The very short time available for wake analysis and the need for recording the buildup and decay of ion and neutral specie concentrations during this time requires a means of displaying repetitive spectral data. This is accomplished by using an oscilloscope with offset trace capability.

In addition, the signal resulting from the residual gas in the ballistic chamber must be suppressed during "neutrals" analysis. The background density of N_2 in either a nitrogen- or air-filled chamber is at least 10^4 to 10^5 times greater than the neutral species of interest. The N_2 ions formed in the source must be suppressed by a "predynode" gating technique to prevent saturation of the electron multiplier. If clean air is used as a background gas in the chamber, a second predynode gate must be employed to remove the O_2^+ peak from the spectrum.

A vacuum system control panel provides fail-safe protection of the vacuum pumps and mass spectrometer against accidental vacuum, power, and water failure. If pressures in the analyzer vacuum system should rise above acceptable levels, gate valves will close automatically, protecting the gas inlet probe, the spectrometer, and the ballistic chamber from contaminating oil vapor. In case of power or cooling water failure, the fail-safe network will automatically isolate the critical regions of the analyzer system.

Special electronics were provided in two general areas: the mass spectrometer ion source and the molecular beam generator inlet probe. Electronics for an ion acceleration region, a lens system, and an ion shutter form a part of the probe assembly. Electronics for improved mass spectrometer operation were added to the ion source.

SYSTEM CHECKOUT AND DELIVERY

The Turbulent Wake Gas Analyzer assembly operation was completed on 5 February 1969. After verifying that the vacuum systems performed properly, the instrument was disassembled and shipped to Lincoln Laboratory on 11 February 1969, along with two operating manuals.

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14. KEY WORDS

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projectile